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Public Release of a One Dimensional Version of the Photon Clean Method (PCM1D)

M. H. Carpenter, J. G. Jernigan

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We thank H. Tananbaum and J. McDowell of the Chandra Science Center, S. Kahn, the RGS/XMM-Newton US team leader, and W. Craig and S. Labov of the I Division of LLNL for their support for the development of the PCM concept. We thank P. Beiersdorfer and the EBIT team for the support to develop the first public version of PCM1D.

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1) Abstract

We announce the public release of a one dimensional version of the Photon Clean Method (PCM1D). This code is in the general class of "inverse Monte Carlo" methods and is specifically designed to interoperate with the public analysis tools available from the Chandra Science Center and the HEASARC. The tool produces models of event based data on a photon by photon basis. The instrument models are based on the standard ARF and RMF fits files. The resulting models have a high number of degrees of freedom of order the number of photons detected providing an alternative analysis compared to the usual method of fitting models with only a few parameters. The original work on this method is described in ADASS 1996 (Jernigan and Vezie).

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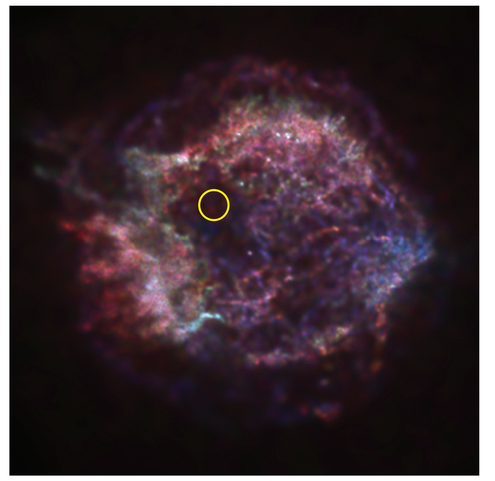
2) Summary

- **Public release of an initial version of PCM1D (beta testing now, release soon)**
- **Models of high dimensionality**
- **Event-based (list-mode) analysis, for both Data and Model**
- **Solves ill-posed problems: selects solution among an infinite set by feedback**
- **Uses Monte-Carlo simulations and bootstrap methods to determine errors**
- **Iteration until quantitative convergence based on a Kolmogorov-Smirnov (KS) test**
- **Lack of convergence may occur, similar to failure of other methods**
- **Compatible with both Bayesian and Frequentist approaches**
- **Interoperates with standard analysis tools (CIAO and FTOOLS)**
- **Reads/writes FITS format files (event data, histograms, ARF, RMF, etc.)**



Fig, 1 -- We choose a single knot in Cas A which has a sufficient number of events in the energy range of interest. The observation used, Chandra ObsID 4638, comprises 167 ks of exposure and totals over 24 million events. The region of extraction is a circle of radius 19.8" centered about RA 23 23 32.0 Dec +58 49 29.6, encircling almost 30k events. The extraction was produced with SAOimage/DS9 and the Chandra provided CIAO tool dmcopy. ARF and RMF files were generated from this reduced event file using the CIAO tool specextract:

```
dmcopy infile="acisf04638_001N001_evt2.fits[EVENTS][sky=region(cut2.reg)][energy=300:4000]" \
        outfile=CasA_4638_cut2_evt2.fits
specextract infile="CaseA_4638_cut2_evt2.fits" outroot=CasA_4638_cut2
```

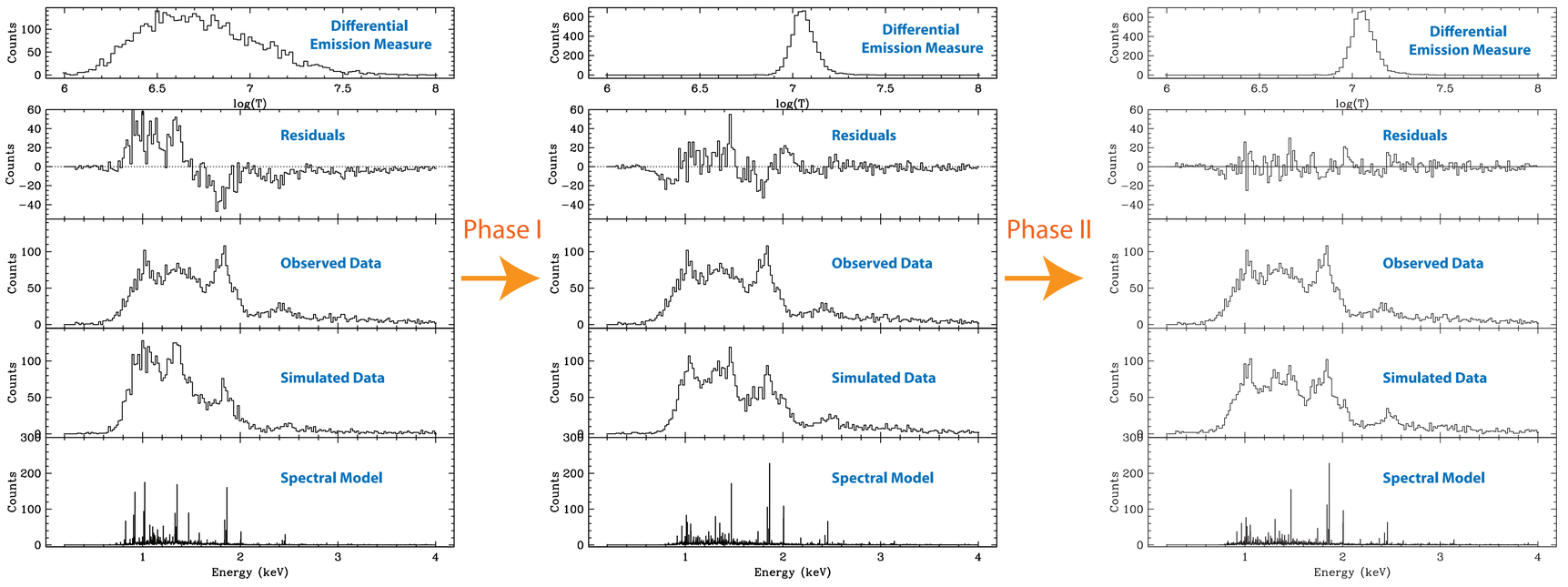
3) Example Analysis: Cassiopeia A (Chandra/ACIS-S Imaging)

The PCM was used to fit a spectrum to a knot in Cas A (see fig. 1), using Observation 4638 from the Chandra X-Ray Observatory. The initial input to PCM1D in this analysis is a blend CIE plasmas with solar abundance and a broad gaussian temperature distribution (see differential emission meaure in fig. 2). The blend of temperature is specified by a model in which each photon of energy E_i has an independently assigned companion temperature of the form $[E_i,T_i]$ where i=1:10,000 (many degrees of freedom). Phase II further reduces the residuals of the Phase I solution by bootstrapping the set E_i taken from the pairs $[E_i,T_i]$ with T_i fixed. The line list with flux estimates from the final solution is shown. The final solution allows for fluxes that are slightly different than solar to reduce the residuals to a level consistent with Poisson noise (compare residuals in fig. 3 and fig. 4). The line flux differentials between the Phase I & II solutions give insight into the proper elemental abundances.

Line List for Final Fit

	Z	Ion	Up	Low	Energy (keV)	Wavelength (A)	Counts	Flux (phot/cm^2)	Flux (erg/cm^2)
1:	Si	13	7	1	1.865e+00	6.647947e+00	215	3.249199e-01	9.708858e-10
2:	Mg	12	4	1	1.472e+00	8.419209e+00	98	1.385000e-01	3.267818e-10
3:	Si	13	2	1	1.839e+00	6.740294e+00	94	1.409944e-01	4.155300e-10
4:	Si	14	4	1	2.006e+00	6.180438e+00	86	1.352553e-01	4.347248e-10
5:	Fe	21	40	1	1.009e+00	1.228400e+01	73	1.294327e-01	2.093069e-10
6:	Fe	21	248	1	1.308e+00	9.479690e+00	60	8.883165e-02	1.861457e-10
7:	S	15	7	1	2.461e+00	5.038726e+00	56	1.336115e-01	5.267473e-10
8:	Si	14	3	1	2.004e+00	6.185849e+00	54	8.384918e-02	2.692643e-10
9:	Fe	22	21	1	1.053e+00	1.177000e+01	54	9.226150e-02	1.557125e-10
10:	Mg	12	3	1	1.472e+00	8.424620e+00	52	7.348981e-02	1.732831e-10
11:	Mg	11	7	1	1.352e+00	9.168750e+00	35	5.108962e-02	1.106883e-10
12:	Fe	23	20	5	1.056e+00	1.173600e+01	34	5.762149e-02	9.753123e-11
13:	Si	13	5	1	1.854e+00	6.688187e+00	32	4.836845e-02	1.436591e-10
14:	Fe	20	58	1	9.652e-01	1.284600e+01	32	5.889943e-02	9.107989e-11
15:	Mg	12	7	1	1.745e+00	7.105774e+00	28	4.306584e-02	1.203929e-10
16:	Fe	22	72	1	1.381e+00	8.974800e+00	27	3.899843e-02	8.631807e-11
17:	S	15	2	1	2.430e+00	5.101501e+00	26	6.221551e-02	2.422591e-10
18:	Fe	21	460	1	1.446e+00	8.574000e+00	25	3.547365e-02	8.218673e-11

List 1 -- Along with a list of model photons, PCM1D also computes a line list with measured fluxes and labeled atomic transitions. The labels for the upper and lower levels are internal designations of the AtomDB, and can be resolved into atomic transitions using the Chandra WebGUIDE at http://cxc.harvard.edu/atomdb/WebGUIDE/



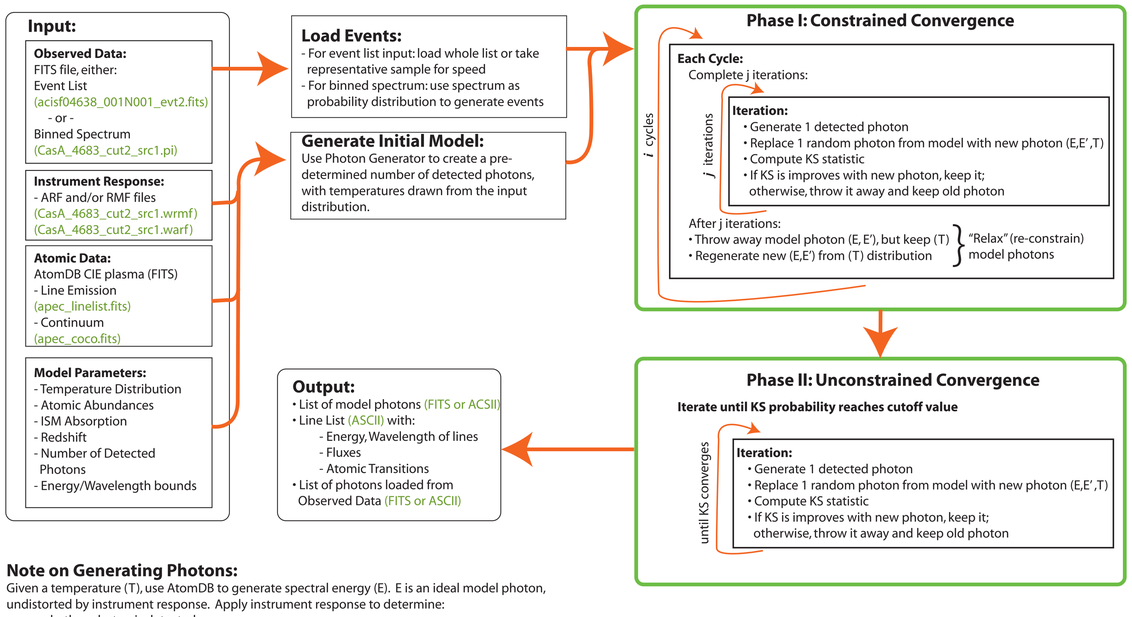
Fig, 2 -- The initial model is generated from a blend of CIE plasmas with a wide gaussian emission measure distribution with a centroid at 4 MK and a standard deviation of $\log_{10}(T) = 0.3$. The poor fit evidenced by the arbitrary initial guess does not affect the convergence of the PCM, only the amount of time required to converge. The simulated data is derived from the spectral model and an instrument model based on specific ARF and RMF files. The observed data is a histogram of the observed ACIS-S events from a portion of level 2 fits event files (EVT2).

Fig. 3 -- The model after Phase I. The algortithm has selected a highly peaked temperature distribution which shows an approximate agreement with the observed data. As the atomic abundances are fixed at solar, we do not expect convergence to a high confidence level. The model has an over-abundance of magnesium (see bright line at 1.47 keV), as well as an under-abundance of Si (see bright line at 1.865 keV).

Fig. 4 -- Phase II seeks to correct the flux discrepencies in the Phase I residuals (see fig. 3). The final Phase II solution adjusts the intensities of individual lines from the assumed solar level and thereby reduces the residuals to a final level consistent with Poisson noise (see residuals above).

4) Process Flow

Using example inputs from Cas A analysis



Note on Generating Photons:

Given a temperature (T), use AtomDB to generate spectral energy (E). E is an ideal model photon, undistorted by instrument response. Apply instrument response to determine:
- whether photon is detected
- what is its detected pulse height or "energy" (E')

To generate 1 detected photon, PCM1D may need to generate more than one ideal model photon.

5) Proof of Concept: Fitting Simulated Data

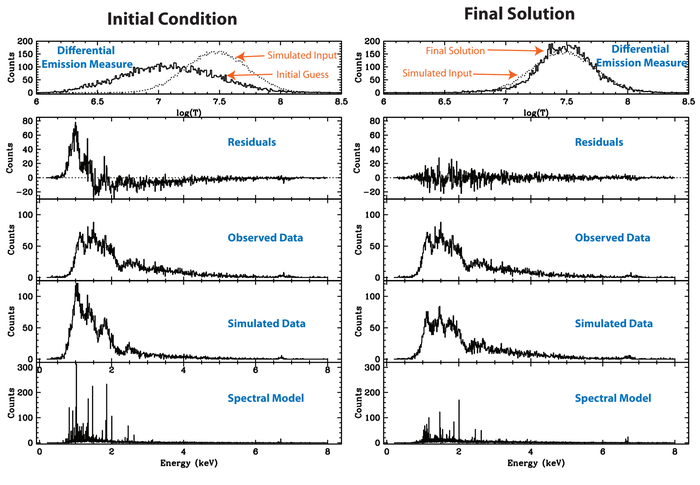


Fig. 5 -- These panels show a PCM fit to a simulated blend of CIE plasmas derived from the AtomDB spectra and Chandra response files. The simulated data is based on a broad gaussian emission measure distribution with a centroid at 30MK and a standard deviation of $\log_{10}(T) = 0.25$ (see dotted line in differential emission measure panels). The intial guess is a differential emission measure distribution with a centroid of 12MK and a very large standard deviation of $\log_{10}(T) = 0.4$. The final solution converges to the correct broad temperature distribution, illustrating that PCM1D finds solutions for problems that require a large number of degrees of freedom.

6) Example: AB Dor (XMM/RGS)

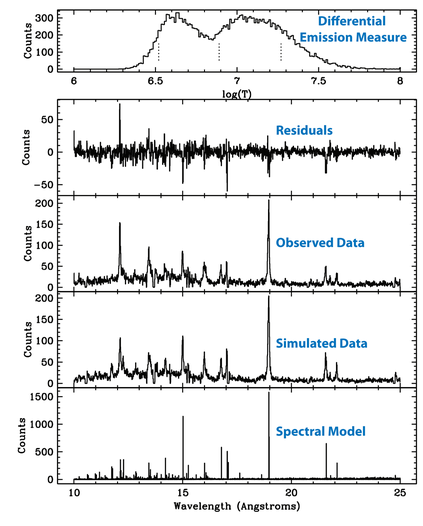


Fig. 6 -- This spectrum was produced from XMM/RGS data of the AB Dor binary provided by A. Rasmussen of the KIPAC/SLAC, Stanford University. The PCM fit was performed assuming a solar abundance of elements. The upper panel showing emission measure vs. T has three dotted lines which mark the three approximately equal components derived using XSPEC (Sanz-Forcada, Maggio, and Micela, A&A 404, 2003). The preliminary Phase II PCM1D solution shown here has 25000 free parameters (one for each photon), compared to the 6 free parameters for the published model (see